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Nonlinear Stochastic Evolution Equations: Analysis, Numerics, and Applications

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Nonlinear Stochastic Evolution Equations: Analysis, Numerics, and Applications

Technische Universität Berlin
December 6 – 8, 2018

Organizers:
Etienne Emmrich (Berlin), Eduard Feireisl (Prague/Berlin),
Raphael Kruse (Berlin)

http://www.tu-berlin.de/?spde2018

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Outline

Nonlinear evolution equations are a well-established and powerful tool to model many highly complex physical phenomena. The Navier–Stokes equations describe, besides many other applications, the turbulent flow of a liquid or gas around an obstacle. Further important examples of nonlinear evolution equations include the porous media equation in fluid mechanics, the Cahn–Hilliard equation in metallurgy, or the FitzHugh–Nagumo equation in neuroscience.

This workshop focuses on nonlinear stochastic evolution equations which have gained a lot of attention in stochastic analysis, numerical analysis and PDE theory over the last decades. In uncertainty quantification, one introduces random coefficients or stochastic perturbations into evolution equations to model incomplete knowledge of parameter values. Often, the presence of stochastic noises lead to a low regularity of the exact solution and require new analytical and numerical methods. As one example for such a new approach we mention the rough path theory by T. Lyons and its development into M. Hairer's regularity structures.

Furthermore, the recent breakthrough discoveries in the field of the Euler equations and, more recently, the Navier–Stokes systems based on the application of the method of convex integration stimulate a new interest in basic questions of mathematical fluid mechanics, including a thorough revision of both modelling and suitable concepts of solutions. Here, stochastic methods could be one possible approach to these issues.

The goal of this workshop is to discuss open problems and recent progress made in the mathematical treatment of nonlinear stochastic evolution equations and to offer a fruitful and stimulating environment to foster the exchange of ideas.

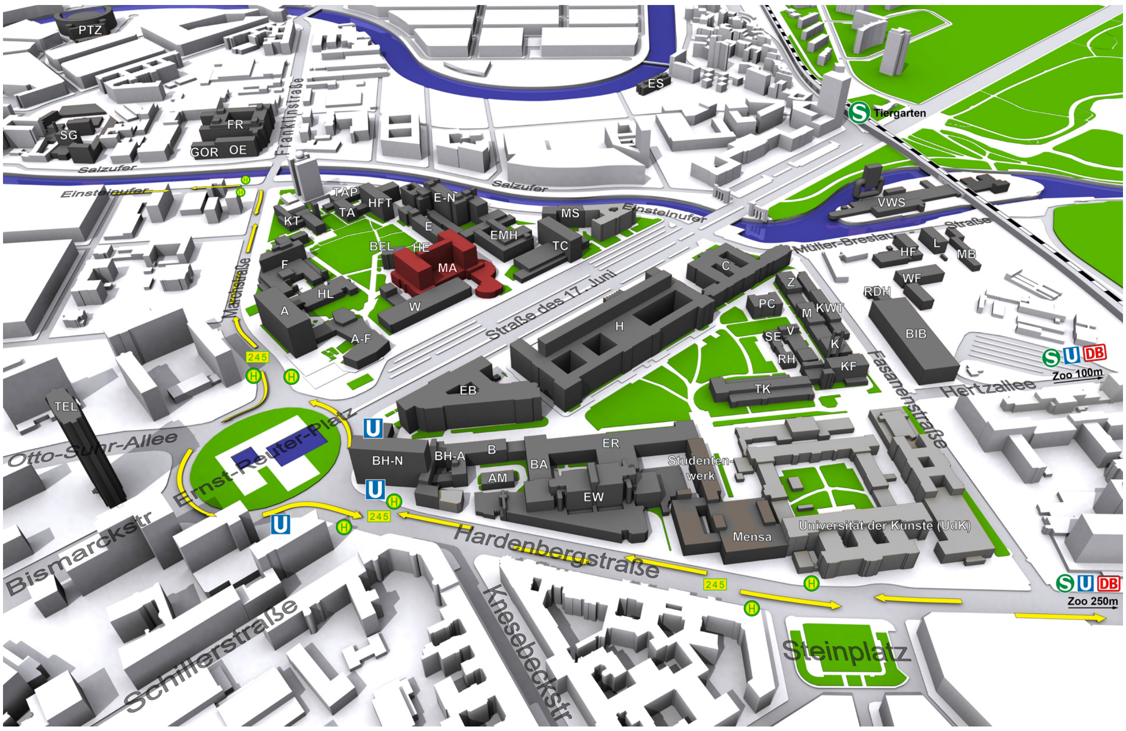
We wish you all an inspiring workshop and a pleasant stay in Berlin.

Eduard, Etienne, and Raphael

Venue: December 6 – 8, 2018

- Room: **MA 415**
- Address: TU Berlin, Math Building, Campus Charlottenburg, Straße des 17. Juni 136, 10623 Berlin
- Travel options:
  - Closest S-Bahn: Tiergarten (S5, S7, S75)
  - Closest U-Bahn: Ernst-Reuter Platz (U2)

Campus Charlottenburg



Internet Access

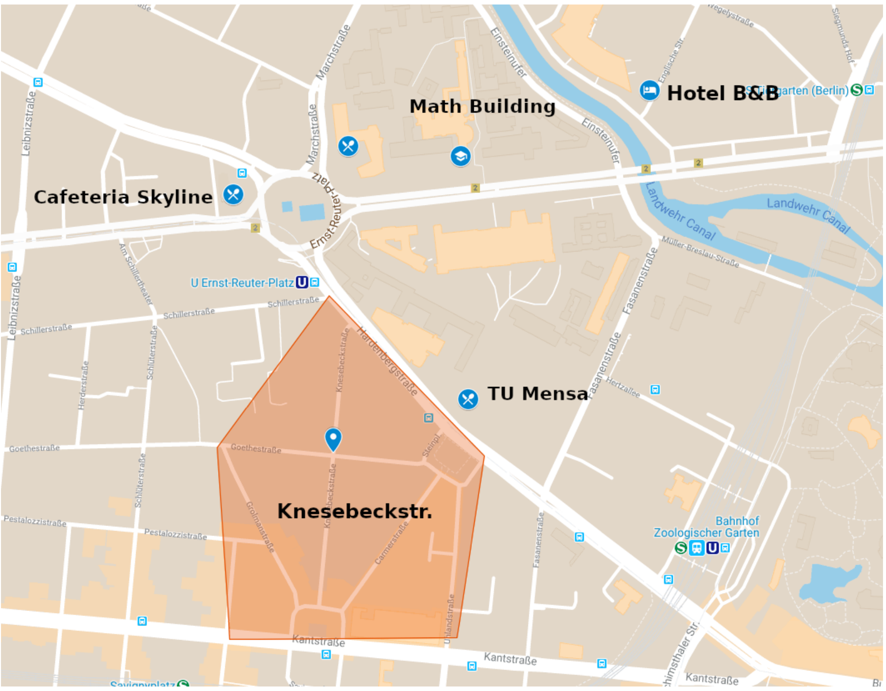
- Eduroam can be used in every facility on the campus.
- Please contact the organizers in case you are in need of an alternative Wifi login.

Lunch Options

There are several options in or close to the Math Building:

- Canteen on the 9th floor of the Math Building.
  http://personalkantine.personalabteilung.tu-berlin.de/
- Cafeteria "Skyline", TU-Hochhaus (TEL), Ernst-Reuter-Platz 7.
  https://www.stw.berlin/mensen/mensa-tu-skyline.html
- Mathe-Café, next to the main entry of the Math Building, offers, e.g., sandwiches and warm Indian dishes.
- TU-Mensa, Hardenbergstraße 34 (close to Steinplatz).
  https://www.stw.berlin/mensen.html
- Several restaurants and bakeries are found in Knesebeckstraße and its surrounding (about 10 min walk).

Please take note that the first four options are closed on Saturday.



Conference Dinner

- **Thursday 19:15** in the restaurant **Neugrüns Köche**, Schönhauser Allee 135, 10437 Berlin
- Bus transfer: departure at **18:45** in front of the Math Building
- Travel option for return: U-Bahn Eberswalder Straße (U2)

	Thursday	Friday	Saturday
Venue	**Room: MA 415, Straße des 17. Juni 136**	**Room: MA 415, Straße des 17. Juni 136**	**Room: MA 415, Straße des 17. Juni 136**
10:00–10:45	*Numerical approximation of the stochastic Cahn-Hilliard equation and the (stochastic) Hele-Shaw problem* L'ubomír BAŇAS	*Random initial conditions and noise in 2D Euler equations* Franco FLANDOLI	*Stochastic PDEs Driven by Noise with Memory* Bohdan MASLOWSKI
10:45–11:30	*Theoretical study and numerical simulation of pattern formation in the deterministic and stochastic Gray-Scott equations* Mechthild THALHAMMER	*On strong convergence of time numerical schemes for the stochastic 2D Navier-Stokes equations* Annie MILLET	*Time-fractional stochastic conservation laws* Petra WITTBOLD
11:30–12:00	*— Coffee Break —*		
12:00–12:45	*SPDE simulation on spheres* Annika LANG	*Space-time adaptivity for Stochastic PDEs* Andreas PROHL	*Existence, uniqueness and stability of semi-linear rough partial differential equations* Wilhelm STANNAT
12:45–14:30	*— Lunch Break —*		
14:30–15:15	*On regularity results for some Kolmogorov equations in infinite dimension* Charles-Edouard BRÉHIER	*On Recent Progress in Dynamics of Reaction-Diffusion Equations* Christian KÜHN	*Hydrodynamic limit of kinetic equations with environmental noise* Julien VOVELLE
15:15–16:00	*On temporal regularity for SPDEs in Besov-Orlicz spaces* Martin ONDREJÁT	*Generation of random dynamical systems for SPDE with nonlinear noise* Benjamin GESS	*On some stochastic nonlocal equations* Guy VALLET
16:00–16:45	*— Coffee Break —*		
16:45–17:30	*Fluctuations for point vortex models* Marco ROMITO	*Stochastic Neural Mass Models through Structure-Preserving Approximate Bayesian Computation* Evelyn BUCKWAR	
17:30–18:15	*Markov selection for the stochastic compressible Navier–Stokes system* Martina HOFMANOVÁ		
19:15	*—Conference Dinner— (Bus transfer 18:45)*		

Abstracts

L'ubomír BAŇAS

Numerical approximation of the stochastic Cahn-Hilliard equation and the (stochastic) Hele-Shaw problem

The Cahn-Hilliard equation is a fourth oder parabolic partial differential equation (PDE) that is widely used as a phenomenological model to describe the evolution of interfaces in many practical problems, such as, the microstructure formation in materials, fluid flow, etc. It has been observed in the engineering literature that the stochastic version of the Cahn-Hilliard equation provides a better description of the experimentally observed evolution of complex microstructure. The equation belongs to a class of so-called phase-field models where the interface is replaced by a diffuse layer with small thickness proportional to an interfacial thickness parameter ϵ. It can be shown that for vanishing interfacial thickness the deterministic as well as the stochastic Cahn-Hilliard equation (with proper scaling of the noise) both converge to a sharp-interface limit which is given by the deterministic Hele-Shaw problem. We propose a time implicit numerical approximation of the stochastic Cahn-Hilliard equation which is robust with respect to the interfacial thickness parameter. We show that, with suitable scaling of the noise, the sharp-interface limit of the proposed numerical approximation converges to the deterministic Hele-Shaw problem. In addition we present numerical evidence that without the scaling of the noise the sharp-interface limit of the stochastic Cahn-Hilliard equation is a stochastic version of the Hele-Shaw problem. We propose a numerical approximation of the stochastic Hele-Shaw problem and present computational results which demonstrate the respective convergence of the stochastic Cahn-Hilliard equation to the deterministic or the stochastic version of the Hele-Shaw problem depending on scaling of the noise term.
This is joint work with D. Antonopoulou, R. Nurnberg and A. Prohl.

Charles-Edouard BRÉHIER

On regularity results for some Kolmogorov equations in infinite dimension

We consider the function $u(t,x) = \mathbb{E}[\phi(X(t,x))]$, defined for $t \geq 0$, $x \in H$, where $X(t,x)$ is the solution of a parabolic, semilinear, SDPE $dX(t) = AX(t)dt + F(X(t))dt + \sigma(X(t))dW(t)$, $X(0) = x$, with values in the infinite dimensional Hilbert space H.

At a formal level, u solves the Kolmogorov equation $\partial_t u = Lu$, with the initial condition $u(0,\cdot) = \phi$, where L is the associated infinitesimal generator.

The goal of this talk is to exhibit the properties on spatial derivatives of u which are required to give a meaning to the expression Lu, and to analyze the weak error for the numerical discretization of X. In addition, we will present new methods to prove this type of results, in two cases: additive noise and F not globally Lipschitz continuous (joint work with L.Goudenège), and multiplicative noise (nonlinear diffusion coefficient σ, joint work with A.Debussche).

Evelyn BUCKWAR

Stochastic Neural Mass Models through Structure-Preserving Approximate Bayesian Computation

Franco FLANDOLI

Random initial conditions and noise in 2D Euler equations.

After a review about a recent new approach to incompressible 2D Euler equations with random initial condition and transport noise, we show that a special scaling limit of the stochastic Euler equations leads to the stochastic Navier-Stokes equations with additive space-time white noise. Remarkable is the difference of the noise. And the inversion with respect to usual paradigm that considers Euler equations as limit of Navier-Stokes equations. It is based on joint work with Dejun Luo.

Benjamin GESS

Generation of random dynamical systems for SPDE with nonlinear noise

In this talk we will revisit the problem of generation of random dynamical systems by solutions to SPDE. Despite being at the heart of a dynamical system approach to stochastic dynamics in infinite dimensions, most known results are restricted to SPDE driven by affine linear noise, which can be treated via transformation arguments. In contrast, in this talk we will address instances of SPDE with nonlinear noise, with particular emphasis on porous media equations driven by conservative noise

Martina HOFMANOVÁ

Markov selection for the stochastic compressible Navier–Stokes system

We analyze the Markov property of solutions to the compressible Navier–Stokes system perturbed by a general multiplicative stochastic forcing. We show the existence of an almost sure Markov selection to the associated martingale problem. Our proof is based on the abstract framework introduced in [F. Flandoli, M. Romito: Markov selections for the 3D stochastic Navier—Stokes equations. Probab. Theory Relat. Fields 140, 407–458. (2008)]. A major difficulty arises from the fact, different from the incompressible case, that the velocity field is not continuous in time. In addition, it cannot be recovered from the variables whose time evolution is described by the Navier–Stokes system, namely, the density and the momentum. We overcome this issue by introducing an auxiliary variable into the Markov selection procedure.

Christian KÜHN

On Recent Progress in Dynamics of Reaction-Diffusion Equations

In this talk, I am going to provide a survey of some recent progress on dynamics of certain (still relatively elementary) classes of reaction-diffusion SPDEs. Even the basic theory of what a "solution" should be is still under very active development and discussion; here I shall mention recent progress made for quasi-linear and nonlocal SPDEs [1, 2]. Then I shall focus in more detail on how to capture local fluctuations near deterministically stationary solutions from an analytical [3, 4] and a numerical standpoint [5–7]. Time permitting, I am going to provide a brief outlook towards the case of travelling waves [8].

The talk is based upon a series of works with several co-authors [1–8].

References

[1] N. Berglund and C. Kuehn. "Regularity structures and renormalisation of FitzHugh-Nagumo SPDEs in three space dimensions". *Electronic Journal of Probability*, Vol. 21, No. 18, pp. 1–48, 2016.

[2] C. Kuehn and A. Neamtu. "Pathwise mild solutions for quasilinear stochastic partial differential equations". arXiv: `1802.10016`, 2018.

[3] K. Gowda and C. Kuehn. "Early-warning signs for pattern-formation in stochastic partial differential equations". *Communications in Nonlinear Science and Numerical Simulations*, Vol. 22, No. 1, pp. 55–69, 2015.

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[7] C. Kuehn and P. Kuerschner. "Combined Error Estimates for Local Fluctuations of SPDEs". arXiv: `1611.04629`, 2016.

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Annika LANG

SPDE simulation on spheres

The simulation of solutions to stochastic partial differential equations requires besides discretization in space and time the approximation of the driving noise. This problem can be transferred to the simulation of a sequence of random fields on the underlying domain. In this talk I will concentrate on domains that are spheres and review some recent developments.

Bohdan MASLOWSKI

Stochastic PDEs Driven by Noise with Memory

The talk is based on several recent papers by P. Coupek, B. Maslowski and their collaborators.

By processes with memory we understand a broad class of so-called Volterra processes in infinite dimensions which (beside the standard Brownian motion) include, for example, fractional and multifractional Brownian motions and the Rosenblatt process in infinite dimensions. After developing basic tools of stochastic analysis with respect to these processes (including also the Ito formula for Rosenblatt process) we study regularity and basic properties of stochastic convolution integrals and apply the results to SPDEs. We also study the large time behaviour for linear SPDEs (and in Gaussian case of equations with bilinear noise term) and its dependence on the type of noise.

Annie MILLET

On strong convergence of time numerical schemes for the stochastic 2D Navier-Stokes equations

We prove that some time discretization schemes, such as the splitting, fully and semi-implicit ones, of the 2D Navier-Stokes equations subject to a random perturbation converge "strongly", that is in the set of square integrable random variables. The speed of convergence depends on the viscosity. The argument is based on convergence of a localized scheme, and on exponential moments of the solution to the stochastic 2D Navier-Stokes equations. This joint work with H. Bessaih improves previous results which only described the speed of convergence in probability of these numerical schemes.

Martin ONDREJÁT

On temporal regularity for SPDEs in Besov-Orlicz spaces

We show that paths of solutions to parabolic stochastic differential equations have the same regularity in time as the Wiener process (as of the current state of art). The temporal regularity is considered in the Besov-Orlicz spac $B^{1/2}_{\Phi_2,\infty}(0,T;X)$ where $\Phi_2(x) = \exp(x^2) - 1$ and X is a 2-smooth Banach space. This is a joint work with Mark Veraar.

Andreas PROHL

Space-time adaptivity for Stochastic PDEs

I propose a new adaptive time stepping method to numerically solve a general SPDE, where local step sizes are chosen in regard of the distance between empirical laws of time iterates and extrapolated data. Time adaptivity is then complemented by a local refinement/coarsening strategy of the spatial mesh via a stochastic version of the ZZ-estimator. Next to an improved accuracy, we observe a significantly reduced empirical variance of standard estimators, and therefore a reduced sampling effort. The performance of the adaptive strategies is studied for SPDEs with linear drift, including the convection-dominated case where the streamline diffusion method is adopted to attain a stable discretization, and a nonlinear SPDE where approximate solutions exhibit discrete blow-up dynamics. - This is joint work with C. Schellnegger (U Tübingen).

Marco ROMITO

Fluctuations for point vortex models

The first part of the presentation is a short review of the statistical mechanics theory for points vortex models for the 2D Euler equations. In the second part we outline a recent result obtained in collaboration with F. Grotto (Scuola Normale, Pisa) about the fluctuations of the mean field limit for point vortices. In the last part we outline an extension of the theory to a slightly more general class of models (generalized SQG) with more singular interaction. This is a work in collaboration with C. Geldhauser (Chebychev Laboratory, St. Petersburg).

Wilhelm STANNAT

Existence, uniqueness and stability of semi-linear rough partial differential equations

We prove well-posedness and rough path stability of a class of linear and semi-linear rough PDE's using the variational approach. This includes well-posedness of (possibly degenerate) linear rough PDE's in L^p and then – based on a new method – energy estimates for non-degenerate linear rough PDE's. We accomplish this by controlling the energy in a properly chosen weighted L^2-space, where the weight is given as a solution of an associated backward equation. These estimates then allow us to extend well-posedness for linear rough PDE's to semi-linear perturbations.

As a particular example we consider the generalized viscous Burgers equation perturbed by a rough path transport noise.

The talk is based on joint work with P. Friz, A. Hocquet and T. Nielsen from TU Berlin.

References

[1] P. Friz, T. Nilssen, and W. Stannat. "Existence, uniqueness and stability of semi-linear rough partial differential equations". arXiv: 1809.00841.

[2] A. Hocquet, T. Nilssen, and W. Stannat. "Generalized Burgers equation with rough transport noise". arXiv: 1804.01335.

Mechthild THALHAMMER

Theoretical study and numerical simulation of pattern formation in the deterministic and stochastic Gray-Scott equations

Mathematical models based on systems of reaction-diffusion equations provide fundamental tools for the description and investigation of various processes in biology, biochemistry, and chemistry; in specific situations, an appealing characteristic of the arising nonlinear partial differential equations is the formation of patterns, reminiscent of those found in nature. The deterministic Gray–Scott equations constitute an elementary two-component system that describes autocatalytic reaction processes; depending on the choice of the specific parameters, complex patterns of spirals, waves, stripes, or spots appear.

In the derivation of a macroscopic model such as the deterministic Gray–Scott equations from basic physical principles, certain aspects of microscopic dynamics, e.g. fluctuations of molecules, are disregarded; an expedient mathematical approach that accounts for significant microscopic effects relies on the incorporation of stochastic processes and the consideration of stochastic partial differential equations.

In this talk, I will study the stochastic Gray–Scott equations driven by independent spatially time-homogeneous Wiener processes. Under suitable regularity assumptions on the prescribed initial states, existence as well as the uniqueness of the solution processes, is proven. Numerical simulations based on the application of a time-adaptive first-order operator splitting method and the fast Fourier transform illustrate the formation of patterns in the deterministic case and their variation under the influence of stochastic noise.

Guy VALLET

On some stochastic nonlocal equations

In this talk, we will be interested in the well-posedness, and the stability of the entropy solution, for a stochastic fractional-parabolic problem with a first order nonlinear operator.

Julien VOVELLE

Hydrodynamic limit of kinetic equations with environmental noise

We give several results of hydrodynamic limits of stochastic kinetic equations. We are particularly interested by the regime of diffusion approximation, where the noise allows to consider terms with a much more singular amplitude than in the deterministic case. We will explain these differences. Works in collaboration with Caillerie, Debussche, Hofmanova, Rosello.

Petra WITTBOLD

Time-fractional stochastic conservation laws

We consider time-fractional scalar conservation laws of the form

$$dg_{1-\alpha} * (u - u_0) + \operatorname{div} f(u)dt = I^{1-\beta} h dW,$$

where $g_{1-\alpha} = \frac{t^{-\alpha}}{\Gamma(1-\alpha)}$ $(\alpha \in (0,1))$, i.e.

$$\partial_t g_{1-\alpha} * (u - u_0) = \partial_t^\alpha (u - u_0)$$

is the fractional time-derivative in the sense of Riemann-Liouville,

$$f : \mathbb{R} \to \mathbb{R}^N \text{ is a smooth function, and}$$

$I^{1-\beta}$ is the fractional integral of order $1-\beta$ in the sense of Riemann-Liouville ($\beta = 1$ corresponds to the classical additive stochastic noise hdW with a given function h and $W = (W(t), \mathcal{F}_t, 0 \leq t \leq T)$ one-dimensional Brownian motion on a classical Wiener space).

Under certain assumptions on α and β we prove existence and uniqueness of stochastic entropy solutions for arbitrary L^2-initial data.

An interesting open question is whether it is possible to generalize these results to the case of a multiplicative stochastic noise. The main difficulty is that an Itô type formula is not known to exist in the time-fractional derivative case.

This is a joint work with Martin Scholtes.

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